From Plants to Coal: An Introduction to Coal Formation & Identification

SCIENCE CONCEPTS

- Law of Conservation of Matter and Energy: Matter and energy are neither created nor destroyed; they only change form.
- Large-scale dynamic forces, event and processes affect the Earth's land, water and atmospheric systems: rock cycle

OBJECTIVE

Students will learn about coal, a combustible (burnable) rock and its formation from plant matter. It contains two lessons and activities:

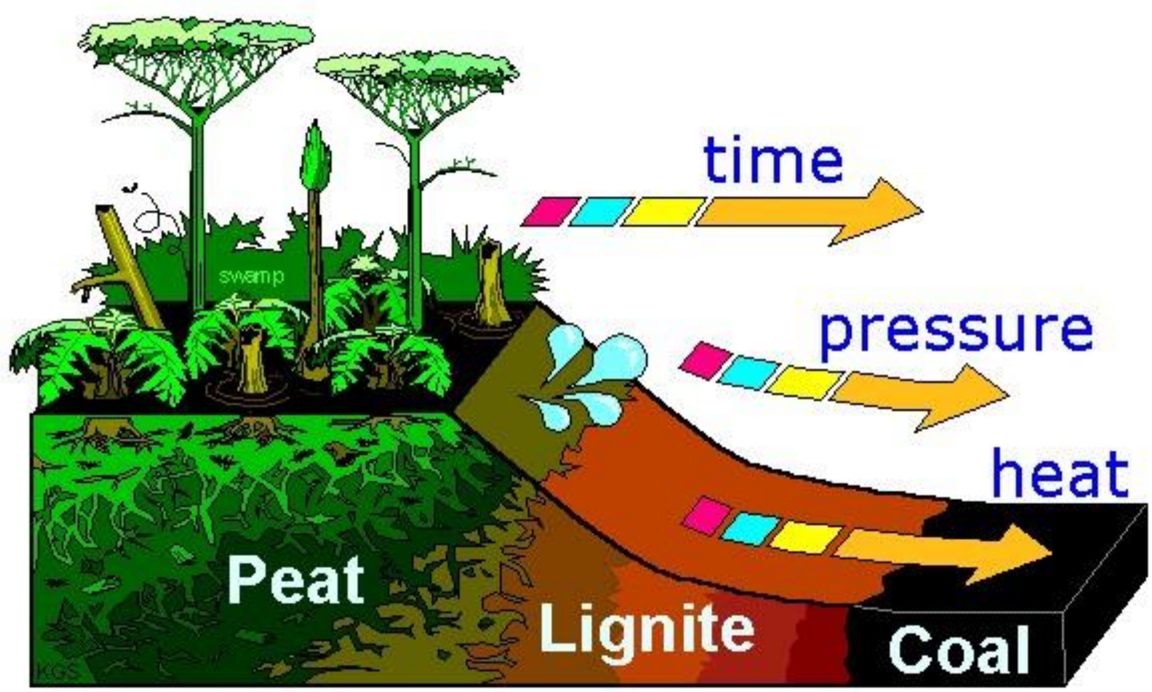
- Lesson 1: How Did Coal Form in Illinois?
- Lesson 2: Look Inside a Chunk of Coal

BACKGROUND INFORMATION

WHAT IS COAL?

The Illinois State Geological Survey (ISGS: www.isgs.uiuc.edu) refers to coal as a "combustible rock" meaning that it will burn when set on fire. They also refer to it as "fossil peat." Peat is partly decayed, moisture-absorbing plant matter found in ancient bogs and swamps. Because peat is only partially decayed, some of the energy of the plants remains trapped in the peat. It is this trapped energy that allows the peat to release heat when it is burned.

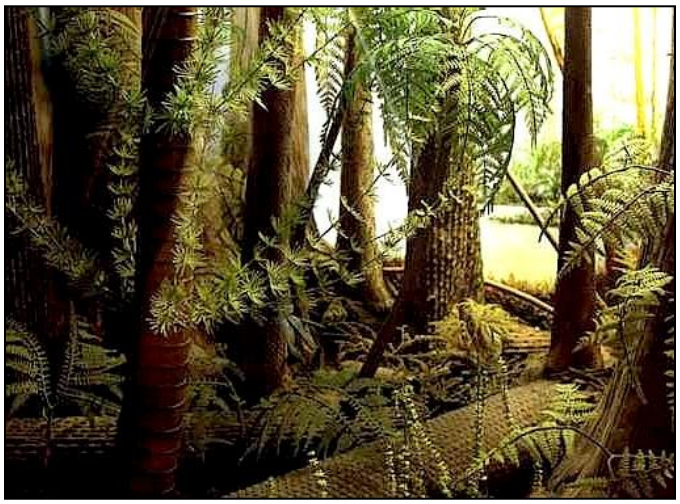
FORMATION OF COAL



Organic matter accumulates in bogs or swamps. The matter is covered with water and sediment and only partially decomposes trapping the energy and forming peat. The peat becomes buried under sediment. Geological processes over long periods of time covered, compressed and altered the decaying plants, gradually transforming this material to coal.

Depending on temperature and pressure differences, the resulting coals contain different percentages of carbon and exhibit different degrees of "hardness." No two coals are exactly alike. Heating value, ash melting temperature, sulfur and other impurities, mechanical strength, and many other chemical and physical properties are dependent upon the plant and animal species and the physical and chemical characteristics of the soil and water in the surrounding environment during coal formation.

ILLINOIS COAL



The formation of Illinois coal began during a part of Geologic Time called the Pennsylvanian Period. (Refer to the Geologic Time Table on p. 9.) During this period, the area that is now called Illinois was near the equator and had a climate much like that of Indonesia today. Tropical climates promoted lush vegetation growth and the subsequent accumulation of plant debris in widespread swamps.

The plants that flourished in these lush swamp forests were somewhat different from the plants we see in today's forests because deciduous (leaf-bearing) trees and flowering plants did not exist. Giant ancestors of today's mosses, ferns, scouring rushes and conifers (cone-bearing trees) grew in these swampy areas. Thriving in a constant tropical climate, these plants grew too fast to exhibit growth rings like our trees today.

Peat, mud and sand were slowly compacted by overlying layers. Eventually, time, pressure and heat transformed the peat into coal and grains of mud and sand were cemented together to produce shales and sandstones.

Viewing a coal high-wall from the side, you might see alternating layers of sandstone, shale and coal. These alternating layers are a record of different environments due to changes in sea level.

FOUR TYPES OF COAL

Coals exhibit a wide range of properties due to:

- the differences in plant materials and mineral matter (i.e. clays, calcite, pyrite and silica)
- the amount of decay of plant materials achieved before burial, and
- the degree of physical and chemical alteration after burial.

Coal Table

Rank	Color/Luster	Texture/ Hardness	Plant Remains	Cleavage	Heat Value in Btu's % of Carbon
Lignite (brown coal)	Dull brownish-black with irregular layers	Powdery, soft	May be present	Crumbles	4,000 to 8,300 Btu's 25% - 35%
Subbituminous	Dull black	Moderate to hard	None	Uneven	8,300 to 11,500 Btu's 35% - 45%
Bituminous (soft coal)	Smooth, shiny black with visible layers	Breaks easily with a hammer	None	Uneven	10,500 to 15,500 Btu's 45% - 86%
Anthracite (hard coal)	Bright black-gray color, glossy, metallic	Hard	None	Uneven to glass-like	15,000 Btu's 86% - 97%

Rank	Location	Availability	Uses
Lignite	Gulf Coast & Northern Plains	About 9% of US coal reserves	Generating electricity
Subbituminous	Western U.S. (MT, WY, CO, NM, AK)	38 % of US coal reserves	Generating electricity
Bituminous	Appalachia & the Midwest Illinois' main coal type	Over 50% of US coal reserves	Generating electricity,; Producing coke for steel industry (not the cola)
Anthracite	Northeastern PA & East Coast	About 2% of US coal reserves	Generating electricity; Heating

Miscellaneous coal facts

Lignite - lowest ranked coal, characterized by high moisture; this is a geologically young coal and tends to crumble when shipped long distances.

Bituminous coal is the most common coal found in the U.S.

Of all the states, Illinois has the largest reported bituminous coal resources.

Different layers are visible in bituminous coal:

Vitrain, or wood material that was preserved, forms a bright, glassy, brittle layer;

Clarain, formed from fine plant debris, with a bright, brittle and satiny texture
Fusain, made from chemically changed wood, with a dull black, charcoal-like appearance

Anthracite is deep black and looks metallic because it is very glossy and shiny. It has the highest carbon content and low volatile matter that burns with a clean flame.

Lesson 1: How Did Coal Form in Illinois?

Background

The Law of Conservation of Matter and Energy states that neither matter nor energy can be created or destroyed. They only change form. Plant material receives the energy it needs to grow through the process of photosynthesis. Under normal methods of decay, the energy stored up in the plant is released through heat. Lack of oxygen and acidic conditions in swamps and bogs deter decomposition, so decaying plants simply accumulate. When organic matter is not allowed to decay completely, the energy becomes trapped. In the case of coal formation, plant matter accumulates in swampy areas and is buried before it decays completely, trapping the energy inside. Over long periods of time, under intense heat and pressure, the compacted plant material is transformed into coal. Coal is known as a fossil fuel.

About 300 million years ago, during the Pennsylvanian Period, Illinois was covered with extensive swamps. These swamps contained an organic material called peat. This organic material, like other living things, contained carbon. When sea level rose, this carbon-laden peat was buried by sediments, condensed by compaction and eventually transformed into coal. Layers of rock, such as, sandstone or shale, form above and below the coal. The coal is sandwiched between the two rock layers. The layer of coal is referred to as a coal seam. (Refer to Depositional History of the Pennsylvanian Rocks in Illinois for more detailed information.)

The process continues today in the swamps of southern Illinois and peat bogs of northeastern Illinois. If buried and left for a few million years, these bogs and swamps may form coal. It takes 10 to 20 feet of peat to form a coal seam one foot thick.

Coal exhibits a wide range of properties due to: the differences in plant material and mineral matter, the amount of alteration of plant materials achieved before burial, and the degree of physical and chemical alteration after burial. Coal is made up almost entirely of carbon, hydrogen, oxygen and nitrogen, and small amounts of iron and sulfur.

There are four main ranks of coal, depending on their carbon content. Lignite is the softest coal and has the lowest heating value. Subbituminous coal, a dull black coal, is ranked between lignite and bituminous. Bituminous coal is ranked third in heating value and carbon content. Anthracite is the highest ranked coal. It has the highest heating value and the most carbon. (See Appendix III for more information on the different ranks of coal.)

The amount of sulfur in coal seems to be related to the kind of rock layers that lie immediately above the coal seam. Coal seams lying under ocean sediments of limestone and black shale consistently contain more than 2.5 percent sulfur. Coal seams beneath gray shale and siltstone that formed in and along major streams and rivers contain less sulfur. Most Illinois coal was formed under ocean sediments and therefore has a relatively high sulfur content.

The sulfur in Illinois coal occurs principally in two forms: as the iron sulfide mineral called pyrite, and as organic sulfur that was present in the original, coal-forming plants that lived about 300 million years ago. Pyrite can be easily removed from the coal by washing the coal and using a float-and-sink separation method. Organic sulfur cannot be removed in the washing process. However, devices called "scrubbers" can remove the sulfur in the flue gas after combustion.

Model

The model will simulate the coal formation process over the course of three days. Teachers may desire for each student to make their own model, or they may wish to make one model for classroom demonstration.

Materials

- -Clay
- -Soil
- -Dried leaf & grass clippings
- -Sand
- -Disposable plastic cups for mixing
- -Clear plastic cup or soda bottle for model
- -Water
- -Elmers glue

Instructions

Day 1

1. Place the sand in a clear plastic cup or soda bottle.
2. Add enough water to make it pourable.
3. Add a couple of squeezes of glue to help create a mixture. The glue represents the cementation that takes place over millions of years.
4. Allow to dry to resemble sandstone.

Day 2

1. Mix soil and dried leaf & grass clippings to a plastic mixing cup.
2. Add enough glue to make the mixture pourable.
3. Pour the mixture on top of the "sandstone" from Day 1.
4. Allow the mixture to dry overnight to simulate the coal layer.

Day 3

1. Place clay in a plastic cup.
2. Add enough water so it will pour.
3. Add a couple of squeezes of glue to help cement the mixture.
4. Pour this over the "coal layer" and allow to dry.

Day 4: Observing the Coal Seam

You have created a layer of coal between two layers of rocks. The bottom part of the cup contains the sandstone. The dark layer represents the coal seam, and the top layer represents the shales that overlie many of Illinois coal seams.

Discussion Questions

1. What happened to the leaves when the layer of clay was added? (They stopped decomposing.)
2. What materials represent deposits (sedimentation) from the sea? (Sand formed sandstone and clay deposits formed shale.).
3. What components are made up of carbon? (All living organisms.)
4. How long would it take for coal to form? (millions of years)
5. Why is coal considered a fossil fuel? (Because the coal contains fossils of dead organisms and the energy in the coal can be used as fuel.)
6. How would engineers determine the quality of the coal layer? (core-sampling, drilling)
7. How could the coal layer be excavated? (surface mining and underground mining)

Extension

Plants: Past & Present

1. How do plants today compare with those living millions of years ago?
2. Refer to Common Pennsylvanian Plants (See Appendix I). Compare pictures of trees or flowering plants that live today to the plants that formed coal.

Construct a Geologic Timeline

1. List significant events while discovering coal's unique niche in the earth's history.
2. Using 1 millimeter = 1 million years, mark the eras and periods using approximately 6 meters of continuous track feed computer paper (or adding machine paper) and the Geologic Timeline information provided. Sketch and label the appropriate organisms that occur for each time period. (See Appendix I)

Simulate Plant Compaction

1. Place a thick, moist sponge in the base of a clear jar and measure the height of the sponge.
2. Add gravel until the sponge is compacted to 1/8 of the original thickness.
3. Imagine the sponge is actually a bunch of dead plants covered by rock. If this sponge were a developing seam of coal, would it provide better fuel at the beginning of this experiment or at the end? Why? How does the presence of moisture impact fuel?

Geologic Time Line

Era	Period	Years Ago (in millions)	Duration (in millions of years)	Length on paper	Major organisms and events
Cenozoic	Quaternary	1.6	1.6	1.6 cm.	modern mammals, woolly mammoth, musk ox, birds; Great Ice Age
	Tertiary	65	63	6.3 cm.	horses, camels, grasslands, primates, whales, rodents; grasslands expand
Mesozoic	*Cretaceous*	144	79	7.9 cm.	mass extinction; gastropods, dinosaurs dominate; ice-free poles
	Jurassic	208	65	6.5 cm.	small mammals, first large dinosaurs, first frogs, toads and salamanders, first bird – Archaeopteryx;
	Triassic	245	40	4.0 cm.	reptile-like birds, ferns, cyads, gingkoes, conifers; continental rifting, climate warms
Paleozoic	Permian	286	41	4.1 cm.	modern insects, dragonflies, beetles, palm trees, large reptiles; Pangaea
	Pennsylvanian	320	34	3.4 cm.	ferns, horsetails, cockroaches; coal-forming sediments in vast swamps
	Mississippian	360	40	4.0 cm.	crinoids, brachiopods, land reptiles, amphibians; glaciation, climate change
	Devonian	408	48	4.8 cm.	spiders, mites, lung fish
	Silurian	438	30	3.0 cm.	leafless plants, first sharks, arthropods
	Ordovician	505	67	6.7 cm.	corals, crinoids, corals, clams, sponges trilobites,
	Cambrian	570	65	6.5 cm.	marine algae; super continent
Precambrian		4,600	4.03 billion	4.03 m.	stromatalites, worms, jellyfish, algae, single-celled organisms

Lesson 2: Coal Identification

Objective
Students will observe and record the physical properties of known coal samples. After the exercise, students will identify unknown coal samples based on the physical properties they observed and recorded earlier.

Materials

Coal samples labeled as lignite, bituminous, and anthracite (the knowns)
Color-coded coal samples of lignite, bituminous, and anthracite (the unknowns)
Paper plates
Hammers
Pieces of cloth to wrap the coal when breaking
Safety goggles
Hand lenses (optional)
Coal Identification Table handout

Instructions
Students will observe the known coal samples and record the physical properties in the Coal Identification Table. After the exercise, students will use their observations to identify unknown coal samples.

Teachers may set up the activity in stations (1 station for each type of coal) and have students rotate through the stations to observe the known coal samples. For large classes, set up 2 identical stations for each type of coal and have students rotate through one set of the stations. The unknown coal samples should be set up in another location for identification when students have completed their observations.

1. Students should wear safety goggles during the activity.
2. Place each of the known coal samples on a paper plate. Label the samples.
3. Wrap each chunk of coal in a piece of cloth and tap with a hammer so it breaks.
4. Examine the coal samples. (A hand lens may be helpful.)
5. Record the properties observed in the Coal Identification Table.
6. After observing the known samples, use properties that were recorded to identify the unknown samples.
7. Caution! Handle coal samples with care. Coal contains sulfur. Some students may have sulfur allergies.
8. Encourage students to wash their hands after handling the coal.

Discussion Questions

1. Which piece of coal broke most easily?
2. What color is the coal that broke most easily?
3. Are parts of plants visible in any of the coals?
4. Would you expect soft coal or hard coal to have a higher heat value? Why? (Hint: Think of a pile of leaves versus a piece of wood. Moist, crumbly coals produce less heat than hard, dry ones.)
5. How would coal hardness affect the mining of the coal?

6. What problems might miners face when mining soft coal? When mining hard coal?
7. What other differences did you observe between the different ranks of coal?

Extension

Grow Coal Crystals

1. Place lumps of coal in a glass dish.
2. Mix together the salt, water, bluing and ammonia.
   Caution: Laundry bluing and ammonia can be hazardous.
   6 Tablespoons salt (uniodized)
   6 Tablespoons laundry bluing
   6 Tablespoons water
   1 Tablespoon ammonia
3. Pour mixture over coal.
4. Sprinkle with a few drops of food coloring (optional).
5. Watch crystals grow.

Coral-like growths are formed by the recrystallization of salt as the liquid evaporates. Coal wicks the salt-saturated liquid up by capillary action and the microscopic bluing particle acts as a nucleus for the salt to recrystallize. The rate of growth depends largely on the humidity of the surrounding environment, taking from hours to days to begin. Placing it near a windowsill may be helpful. To keep the crystals growing, simply add more salt, water, bluing and ammonia from time to time. Try using a control group; grow crystals on Q-tips, limestone gravel, or clay pots and compare.

Coal Identification Table

Directions:
1. Put on safety glasses. Examine the pieces of coal according to your teacher's directions.
2. Select characteristics from the lists below to describe your observations. Record your observations in the corresponding boxes in the table below.
3. When you are finished examining the coal, use your observations to correctly rank each piece of unknown coal.

Color/Luster: Black, brownish-black, gray, bands of color; Luster refers to the way the coal surface reflects light; metallic and non-metallic; non-metallic luster can be described as glassy, pearly, earthy, greasy, or silky.

Texture/Hardness: Powdery, soft, breaks easily with a hammer, scratches with your fingernail, hard, does not break easily

Plant Remains: leaves, stems, or fossils present; none present

To determine the cleavage:
1. Wrap the piece of coal in a soft cloth and GENTLY hit it with a hammer. Record your findings.
2. Does it crumble into powder, break into sharp-edged even chunks, break into uneven glass-like chunks, or break into round pieces?

Rank	Color/Luster	Texture/ Hardness	Plant Remains	Cleavage
Lignite				
Bituminous				
Anthracite				

Unknown sample: A ______________________   B _____________________________   C _________________________

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